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A Photomultiplier Read-Out for the Bausch and Lomb 1.5 Meter Stigmatic Spectrograph

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LABORATORIES DIVISION • AEROSPACE CORPORATION

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ABSTRACT

A photomultiplier read-out for the Bausch and Lomb 1.5 meter stigmatic spectrograph is described. This modification utilizes nine photomultiplier tubes of the side window type which cover the spectral range between 2000 and 7000 A. Each photomultiplier tube examines a spectral range of approximately 7 A, and can cover a range of 1100 A. Details of the mounting, of the fine motion adjustment, and of an inexpensive regulated power supply for the photomultiplier tubes are described. The application of the instrument to determine the apparent gray-body surface temperature indicates that for a 0.001 inch tungsten wire, electrically exploded by a capacitor of 0.5μf charged to an initial voltage of 25,000 volts, the value is 8500 ± 275°K. Calibration of the instrument was achieved by the use of a National Bureau of Standards spectrally calibrated tungsten ribbon lamp.

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I. INTRODUCTION

There are many applications of time-resolved spectroscopy requiring microsecond resolution. These applications include studies of plasma dynamics,[1-3] reaction kinetics, particularly in explosives,[4] high velocity projectiles,[5,6] and the exploding wire phenomena.[7] In each of these phenomena the application of spectroscopic techniques with time resolution represents an important investigative technique. Several commercial instruments are currently available which supply time resolution for selected wavelength positions using photomultiplier read-out, and a few instruments are available which provide time resolution for a continuous spectrum.

The instrument described in this paper is an addition to a commercial film spectrograph, used in the wavelength interval between 1850 and 7400 A to accommodate photomultiplier tubes for making time-resolved measurements at a number of selected wavelengths. It employs tubes of the side window type which will cover the wavelength region between 2000 and 7000 A, and can observe a total of nine positions in this wavelength interval.

Features of this instrument include simple and inexpensive construction. The instrument can be adapted to a standard spectrograph which also is inexpensive and can be purchased by a laboratory which has a limited budget.

II. INSTRUMENT DESIGN

The Bausch and Lomb Model II spectrograph is a stigmatic instrument that uses a concave reflection grating of 1.5 meter focal length. The spectrum is made stigmatic by use of an auxiliary cylindrical lens which projects the 15 mm high slit on a film 10 inches in length. A simplified diagram of the instrument is shown in Fig. 1. The spectral range covered by the instrument is 1850 to 7400 A in two orders. In the first order the range is between 3700 and 7400 A, and in the second order between 1850 and 3700 A. The average plate factor for the instrument in the first order is 14.8 A per mm. A film cassette utilizes 35 mm film in a 10-inch holder to conform to the Rowland circle of 75 cm radius. The effective aperture of the instrument is f/24, computed from the 62 mm square area of the ruling.

To convert the instrument for photomultiplier read-out, the film cassette is removed from the spectrograph and a specially designed mount, supporting two rows of photomultiplier tubes, is installed. The radius of each track is 75 cm, and the entrance slit of each photomultiplier tube is tangent to the Rowland circle. Each tube is supported separately on a special base which can be moved independently along the track. Figure 2 presents a detailed drawing of the base. Tracks are provided at the top and bottom of the cassette for two staggered rows of tubes which allow closer arrangement in the limited, available space. Motion along the track is provided by a special screw drive which contains a coarse motion and a concentric, independently operated fine motion control which can be operated differentially to give extremely fine control of the wavelength positioning. Details of the screw drive are shown in Fig. 3.

Side window photomultiplier tubes are employed as the detectors. Each tube is housed in an opaque cover and has a slit housing to limit the spectral interval observed by the tube. A diffusion screen is provided to yield a diffused image rather than a sharp image on the photocathode since, as Edels and Gambling have reported,[8] the photocathode does not have a uniform response across its

Schematic Diagram of Optical System

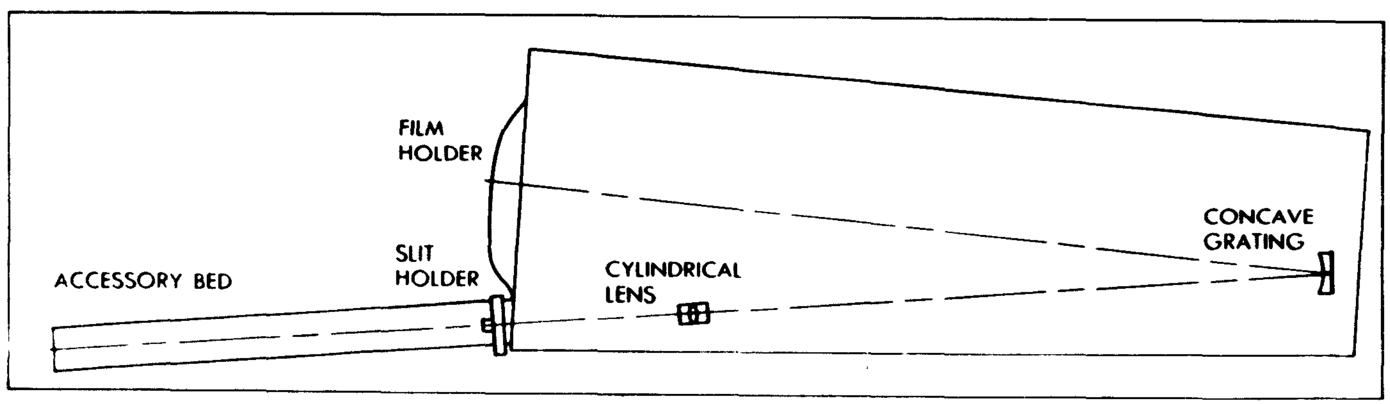

Figure 1. Ray Trace of 1.5 Meter Spectrograph
(Compliments of Bausch and Lomb Inc., Rochester, New York)

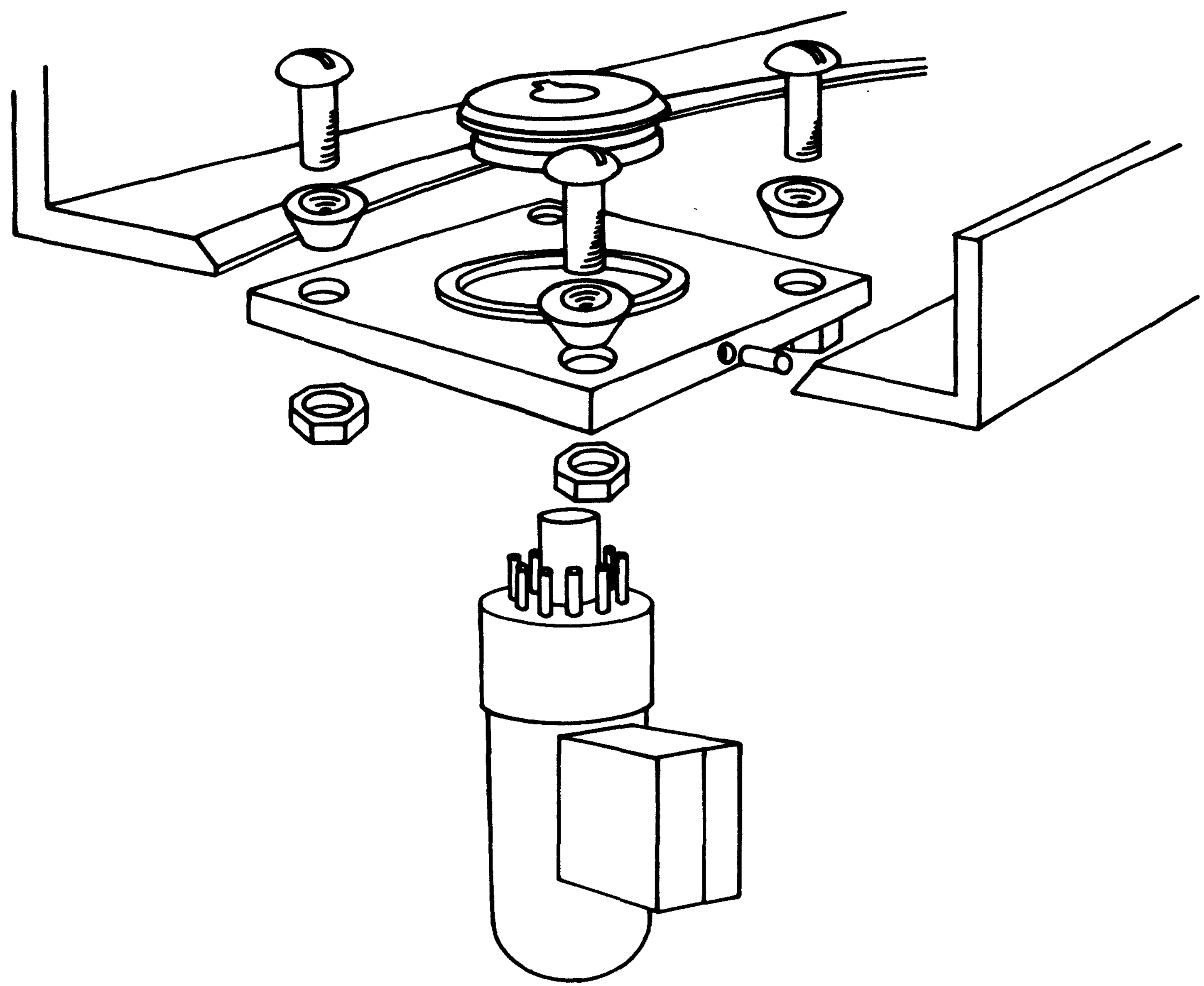

Figure 2. Details of Photomultiplier Base and Support

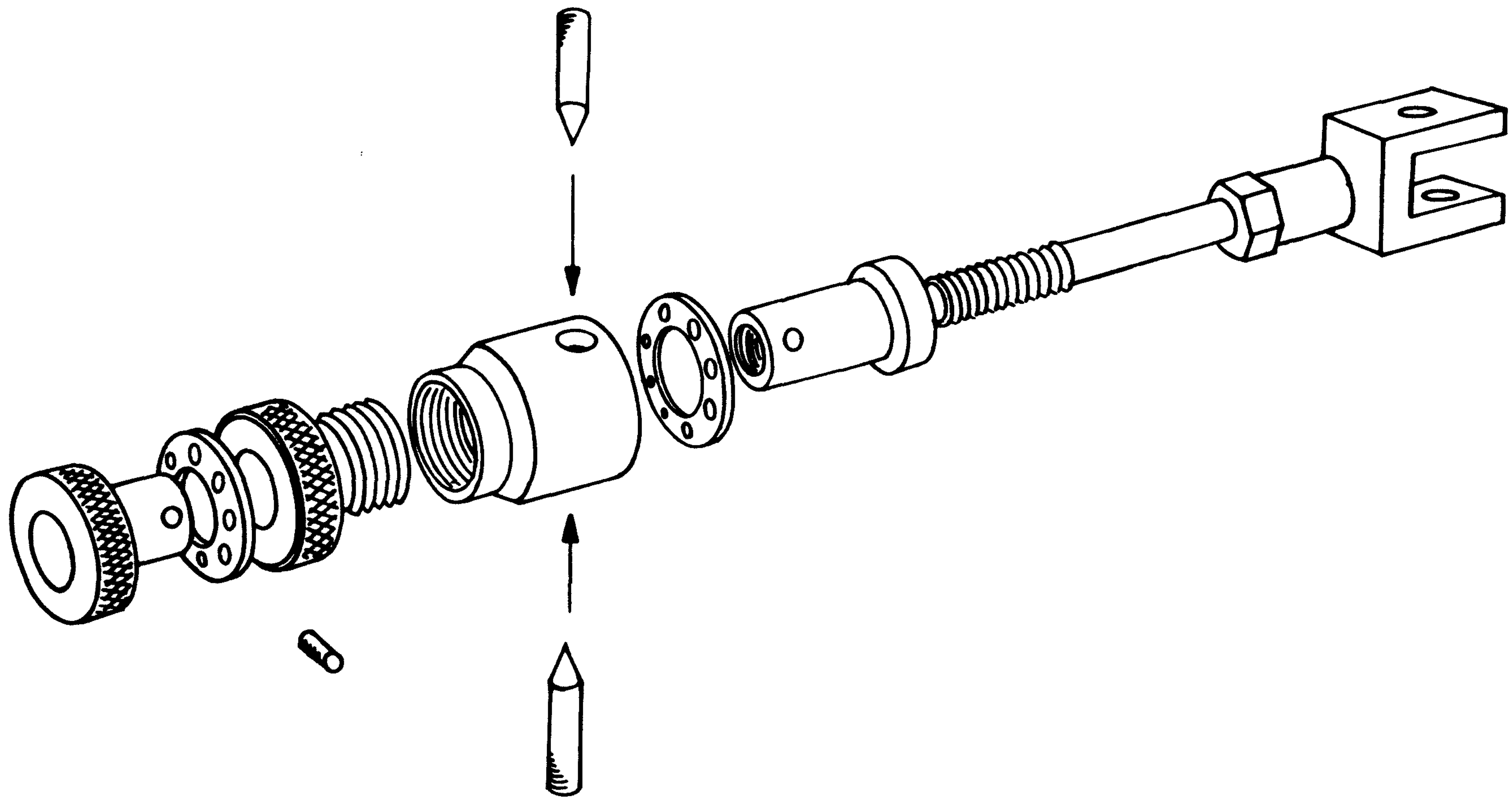

Figure 3. Details of Fine Motion Differential Screw Drive

entire surface. The slits are 0.5 by 22 mm and include a spectral region of 7 A width in the first order. Each tube is separated from its neighboring tube by a distance of 2.1 cm minimum, or 318 A. The maximum distance of travel for each tube is 7.6 cm, or 1130 A. Figure 4 shows the details of the entrance slit and housing of the photomultiplier cassette. The details of the track and base are shown in Fig. 5.

A spectral region between 2000 and 7000 A can be covered by two types of side window photomultiplier tubes. The 1P28 tube, which has an S-5 spectral response, has a peak sensitivity at 3400 A and a lower wavelength cutoff at approximately 2000 A. The 1P21 tube, which has an S-4 response, has a peak sensitivity at 4000 A and an upper wavelength cutoff at approximately 7000 A. These tubes are adequate to cover the principal spectral region of interest and are the most sensitive available side window photomultipliers. The voltage supply for the photomultiplier tubes consists of a regulated power supply and a series of dynode resistors which are wired to the base of the photomultiplier tube socket. An anode resistor is also attached to the tube socket. Thus, the only required internal wiring consists of a high voltage lead-in and a signal lead-out for each tube. Electrical connections through the case were made through BNC connectors which can easily be sealed to prevent the admittance of light.

Fig. 4. Details of Photomultiplier Cassette Showing Photomultipliers in Place on Spectrograph

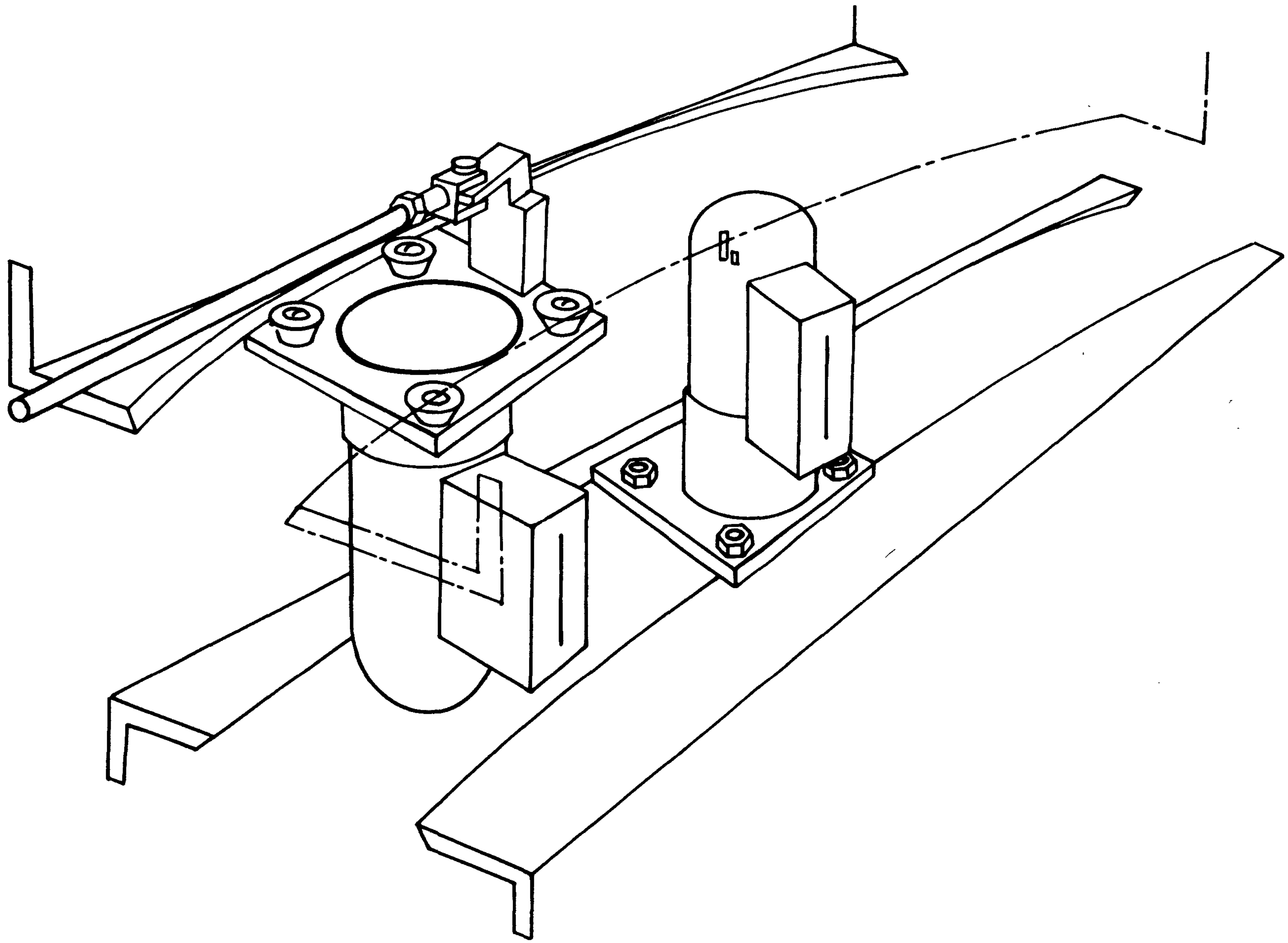

Figure 5. Details of Track, Mount and Photomultiplier Housings

III. INSTRUMENT CALIBRATION

The instrument is calibrated absolutely against a National Bureau of Standards spectrally calibrated lamp. This lamp is designated No. U-64 and can be obtained from NBS. Typically, this lamp is used to calibrate a secondary standard such as the 18-amp tungsten ribbon microscope illuminator, GE18T10/1-6V medium with type SR8 filament, which is then used for periodic checks on the calibration. The use of the secondary tungsten lamp requires correction for the spectral emittance. Correction can be made using the data of DeVos[9] or Larabee[10] on the spectral emittance of tungsten. Since the photomultiplier tubes are sensitive to voltage changes, it is necessary that the dynode voltage be accurately measured at the time of calibration and prior to use. A high voltage regulated power supply has been designed for use with the tubes of this instrument. The power supply is based on an original design by Fellgett.[11] A schematic diagram is shown in Fig. 6. The power supply, which is easily constructed, regulates well for typical variations in the laboratory ac power.

Spectral positions are obtained by reference to standard gas line sources such as neon, mercury or helium which have a number of lines in the interval between 2000 and 10,000 A. The tube is aligned to give maximum reading for a particular reference line. In the event that the tube is moved, it can readily be repositioned.

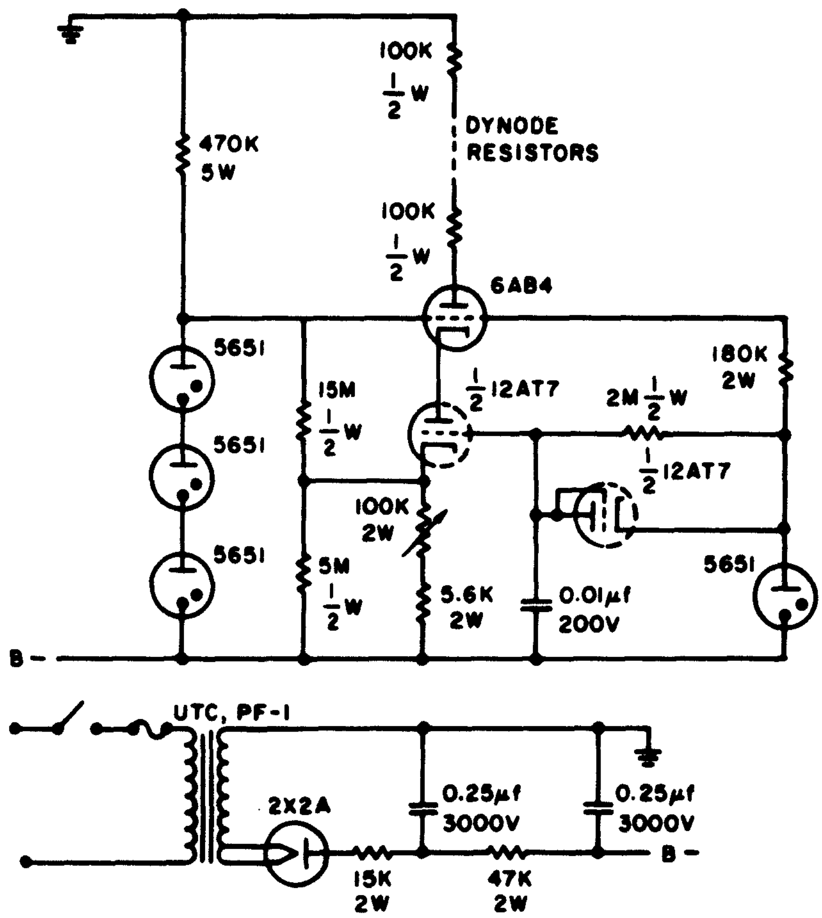

Figure 6. Schematic Diagram of Regulated Power Supply for Photomultiplier Tubes

IV. APPLICATIONS

In using this instrument to investigate exploding wire phenomena, it is possible to obtain time temperature data by observing the luminous intensity at several selected wavelength positions. It is assumed that the surface of the wire during the early stages is a solid or liquid with a spectral distribution similar to tungsten or to a gray body with an emissivity which is not dependent on the wavelength. Based on this assumption, one can determine a surface temperature by assuming either a Planck or Wien distribution law for a gray body or a two-color ratio method. Planck's equation is

$$e_\lambda = \frac{c_1}{\lambda^5 \left[\exp\left(\frac{c_2}{\lambda T}\right) - 1\right]} \tag{1}$$

The spectral data which are obtained are fit by means of Equation (1) using a computer or by using estimates of the best fit from tables of e_λ as a function of temperature. In the two-color ratio method, the ratio of e_λ for the two wavelengths is given by Equation (2).

$$r = \frac{e_{\lambda 1}}{e_{\lambda 2}} = \left(\frac{\lambda_2}{\lambda_1}\right)^5 \exp\left[\frac{c_2}{T\left(\frac{1}{\lambda 2} - \frac{1}{\lambda 1}\right)}\right] \tag{2}$$

Equation (2) can be reduced to:

$$\ln r = A + \frac{B}{T} \tag{3}$$

The values of the constants A and B in Equation (3) are determined by calibrating the instrument with a standard lamp at two temperatures. For a number of tubes the two-color method is reliable because a number of independent ratios can be obtained among the tubes. These ratios are best plotted on

logarithmic graph paper as Temperature versus $R = e_{\lambda 1}/e_{\lambda 2}$ for all possible independent ratios. As an illustration of the applicability of this technique to wires of aluminum, copper and tungsten, an experiment was conducted using this instrument to measure the temperature at the position of maximum radiant intensity of the wire. A schematic diagram of the exploding wire circuit is shown in Fig. 7. It consists of an 0.5 μf capacitor capable of ringing at 25 kv. The measured ringing frequency of the circuit for 0.001 in. wire, 2 cm between electrodes, is experimentally measured as 778 kc. The impedance of this circuit, Z_o, is given by:

$$Z_o = \sqrt{\frac{L}{C}} \tag{4}$$

Assuming that the resistance of the circuit is small compared to the inductive reactance, the ringing frequency is given by:

$$f_r = \frac{1}{2\pi} \sqrt{\frac{1}{LC}} \tag{5}$$

Combining Equations (4) and (5) yields

$$Z_o = \frac{1}{2\pi f_r C} \tag{6}$$

from which the circuit impedance is calculated to be 0.8 ohms. This factor yields an initial current of 30,000 amp. This current is independently measured by means of a Rogowski coil[12] and demonstrated on an oscilloscope. A typical current time waveform is shown in Fig. 8. The experimentally measured current was 31,000 amp, which agreed closely with the calculated current value.

The time luminosity waveform is shown in Fig. 9. The peak occurs at approximately 1.5 μsec after the initiation of the current pulse through the wire. This point occurs after 1-1/2 cycles of the discharge current when approximately

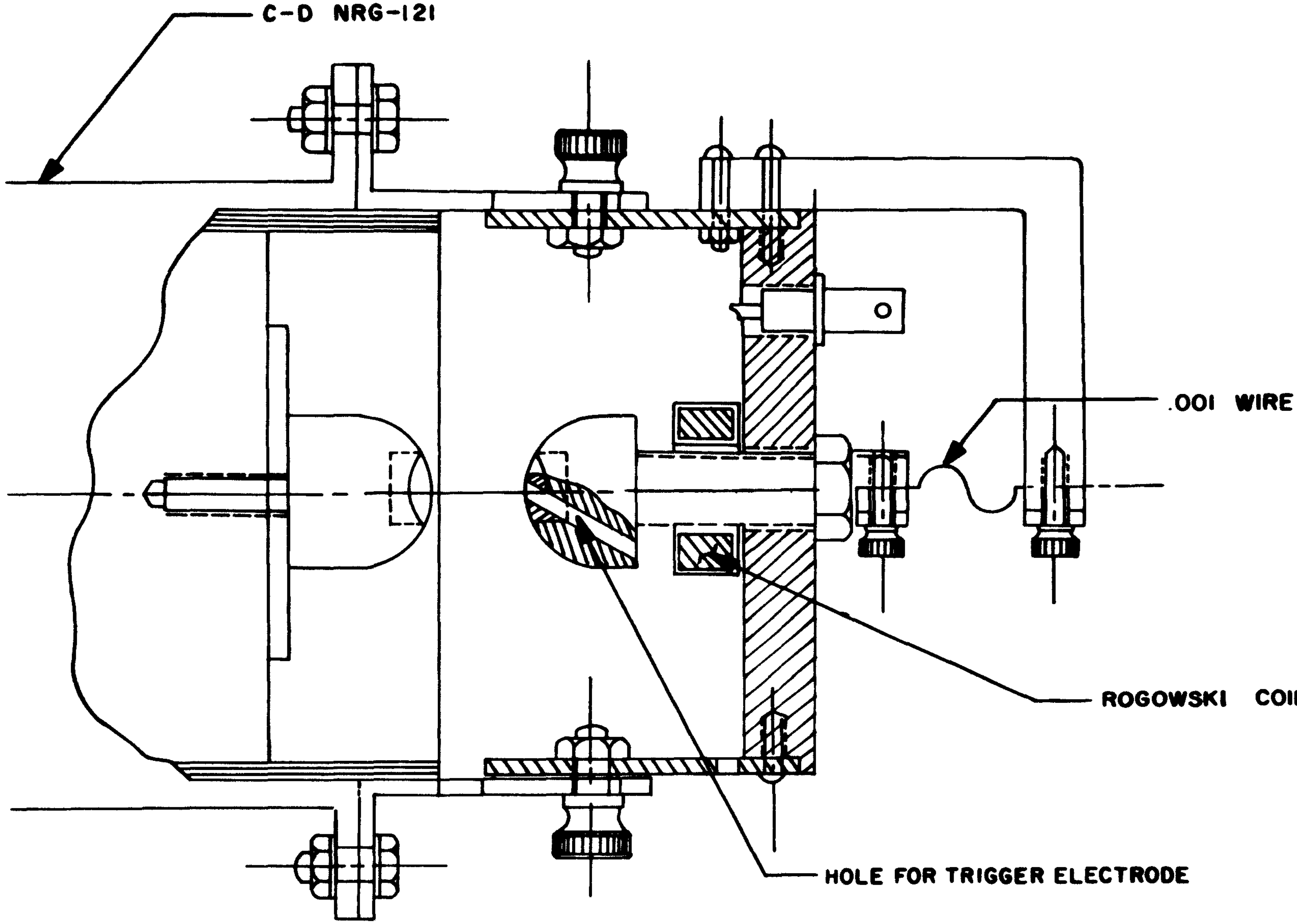

Figure 7. Cutaway of Wire Exploder

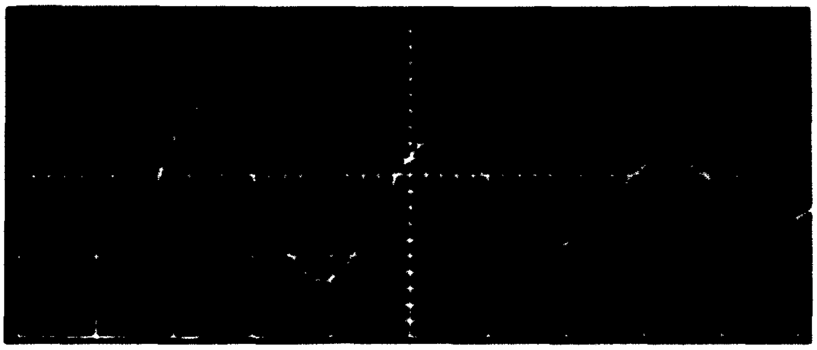

Fig. 8. Current Time Waveform Obtained with Rogowski Coil (Sweep 0.5 μsec per cm)

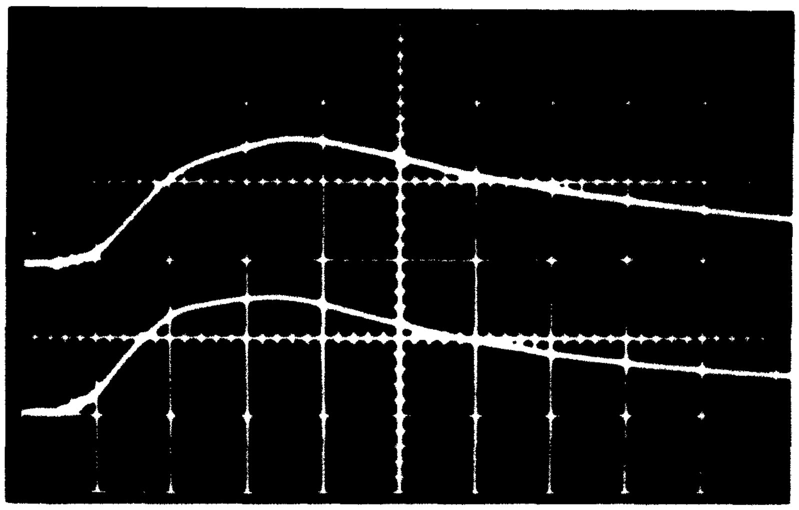

Fig. 9. Luminous Intensity Time Waveform of Exploding Wire (Sweep 0.5 μsec per cm)

60 percent of the energy of the capacitor has been deposited in the wire. Assuming that the energy has been expended in (1) heating the solid wire to a liquid, (2) supplying the heat of fusion, (3) increasing the temperature to the boiling point, (4) supplying the heat of sublimation, and (5) heating a monatomic gas to a final temperature, the calculated temperature would be approximately 100,000°K. The experimentally determined surface temperature was approximately 8500 ± 275°K, which indicates that loss mechanisms of various types such as radiation, circuit impedance, and ionization can account for a significant part of the energy.

V. CONCLUSIONS

The instrument described in this paper is capable of obtaining time-resolved spectra at a number of selected wavelength positions with time resolution on the order of 10^{-8} sec, when used with a high speed oscilloscope. Construction of the instrument is inexpensive and requires a minimum of design and machining. All of the required parts are standard items, readily obtainable. Calibration can be achieved with a tungsten lamp and optical pyrometer since the spectral emissivity of tungsten is known.

ACKNOWLEDGEMENTS

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